World, Regional, Country and New Zealand Electricity Patterns

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ABSTRACT

This paper investigates the patterns of electricity consumption, electricity intensity, electricity intensity curves and electricity intensity factors for various regions of the world and the world total, and selected countries including New Zealand. It was found that the link between economic growth and electricity consumption is stronger in developing countries than those for industrialized countries. The paper also presents sets of forecasts obtained from electricity forecasting models for New Zealand and for the world total electricity consumption.

1. Introduction

Electricity is one of the most dominant forms of energy in human society. Its flexibility as an energy carrier has increased its share in total energy consumed in many countries. This has accelerated economic and social wealth in those countries, through technological innovation and adoption, and increased industrial production.

The heavy dependence of society on electricity requires planning of the resources for generation well in advance of consumption, to ensure a continuous supply of electricity in the future. This in turn requires measurement and determination of the patterns of electricity use to allow prediction of future consumption.

This paper investigates the patterns of electricity consumption, electricity intensity, electricity intensity curves and electricity intensity factors for regions of the world, world total and selected countries. It also presents electricity consumption forecasts for New Zealand and the world total

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2. Electricity Intensity

Electricity intensity is one measure of the amount of electricity that is consumed in an economy as represented by the Gross Domestic Product (GDP). It is expressed as [1],

$$EI = \frac{Consumption}{GDP} \tag{1}$$

A number of underlying factors are reflected by changes in the ratio, such as the state of technology, the price of electricity, the composition of GDP, the levels of activity in individual electricity user sectors, and demographic and sociological factors. Although it is believed that economic growth and electricity demand are linked, the strength of the relation is different from region to region and depends on the stage of development of a country or region. A number of reasons may exist for changes in electricity intensity within a particular sector of industry. They include the growth or decline of electricity-specific end-uses, changes in their efficiency, increases in the use of electricity at the expense of other fuels, or the development of new electricity technology.

The electricity intensity curve (EIC) shows the stage of development of electrical energy in the process of GDP output [1]. The EIC is obtained by graphing the electricity intensity and the level of average personal wealth in a country as measured by GDP per capita. The slope of the curve may assist in determining whether the electrical industry is in a growth, mature or ageing phase.

Each point on the EIC represents a combination of consumption, GDP and population for a particular year. This is called the electricity intensity factor (EIF). These points can be graphed against time. The EIF is defined as,

$$\begin{aligned} EIF &= \frac{Consumption / GDP}{GDP / Population} \\ &= \frac{Consumption \times Population}{GDP^2} \end{aligned} \tag{2}$$

This paper investigates these patterns for regions of the world, world total and selected countries. The world data is divided into eight regions. They are North America (industrialized), Central and South America, Western Europe (industrialized), Eastern Europe and the Former Soviet Union (FSU), Industrialized Asia, Middle East, Africa and developing Asia. The selected countries for this study are New Zealand, United States, United Kingdom, Maldives, China, Japan, Russia, Germany, France, India, Indonesia and Brazil. Apart from New Zealand and the Maldives, all other countries are selected on the basis of being the largest populations, economies or electricity consumptions. The Maldives represents a relatively small developing economy.

3. World Regional Electricity Patterns

Figure 1 shows the electricity consumption in the eight regions of the world from 1980 to 2002.

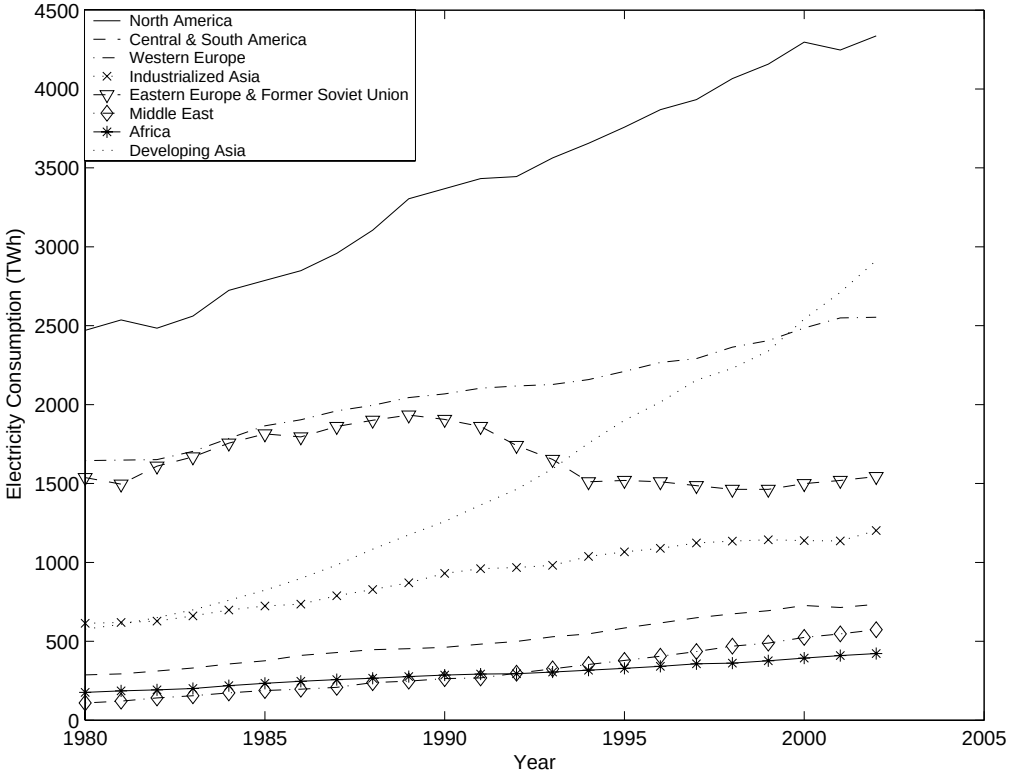

Figure 1 Electricity Consumption in the World (8 regions)

North America consumes the highest amount of electricity throughout the period and at 2002 this region accounts for about 30% of the world electricity consumption. Developing Asia shows the highest rate of growth and by 2002 this region is the second highest electricity consumer. Eastern Europe and the Former Soviet Union show recovery from the economic and social declines of the early 1990s. Africa and the Middle East consume the smallest amounts of electricity. The low electricity consumption in Africa with 14% of the world population indicates the low level of electrification in some countries of this region. In general the electricity consumption in the industrialized countries is increasing at a slower rate than those in the developing world.

4. Electricity Intensity in the Regions of the World

Figure 2 shows the electricity consumption per capita for the regions of the world and the world total. The electricity consumption per capita is the highest for North America. The per capita electricity consumption has gradually increased for all regions except for Eastern Europe and the Former Soviet Union. This is mainly affected by decreases in electricity consumption due to the fall of the Soviet regime, the highest electricity consumer in this region. The per capita electricity consumption is the highest for the industrialized regions.

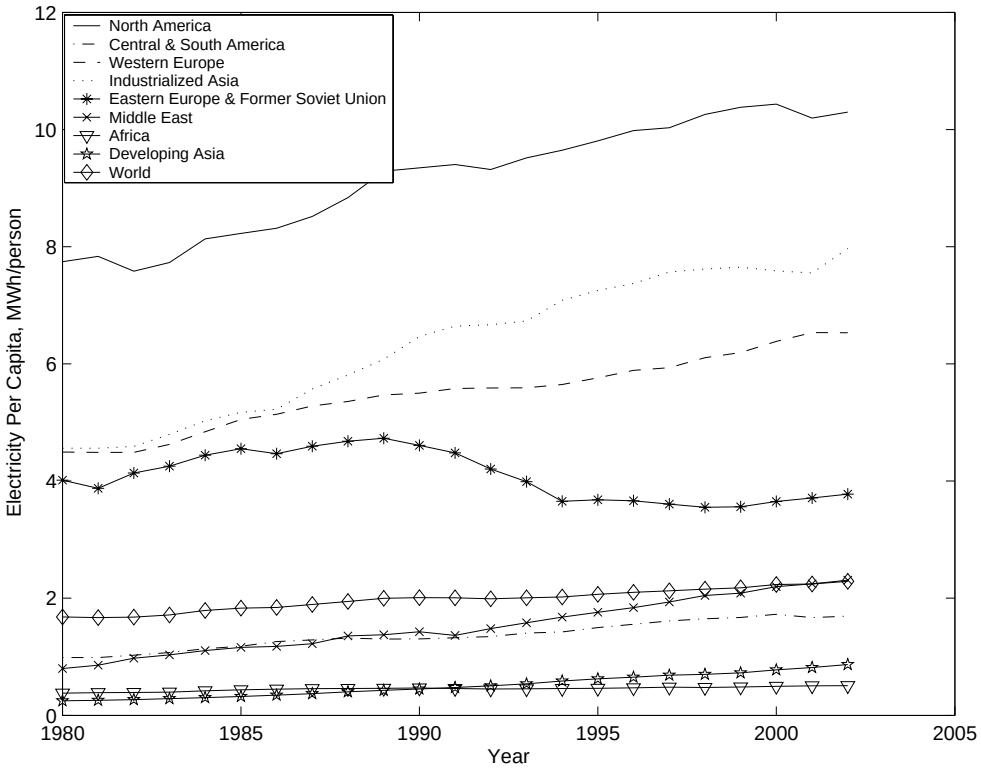

Figure 2 Electricity per capita for the regions of the world and world total

Figure 3 shows the corresponding per capita GDP for the regions. The wealthiest region is not necessarily the most energy intensive. Industrialized Asia has the highest GDP per capita but it has got the second highest electricity consumption per capita. The high GDP per capita is due to that of Japan as compared to Australia and New Zealand in this region.

Figure 4 and 5 show the electricity intensity for the regions of the world and the world total. The electricity intensity in Eastern Europe and the Former Soviet Union is the highest and most varying. There is a sudden decrease in the early 1990s reflecting the break up of the Soviet Union and its transition from a centralized planned system towards a more free market economy. However, even after the fall of the Soviet regime, this region has still got the highest electricity intensity with a decreasing trend.

The developing regions of the world reflect an increasing intensity over the years. The fastest growth is observed in the Middle East. Irrespective of these trends, the world average electricity intensity has been at a near constant level of around 0.4 kWh/US$ (1995) for more than 20 years, reflecting the dominance of Industrialized Asia, Western Europe and North America which display very constant levels over the period.

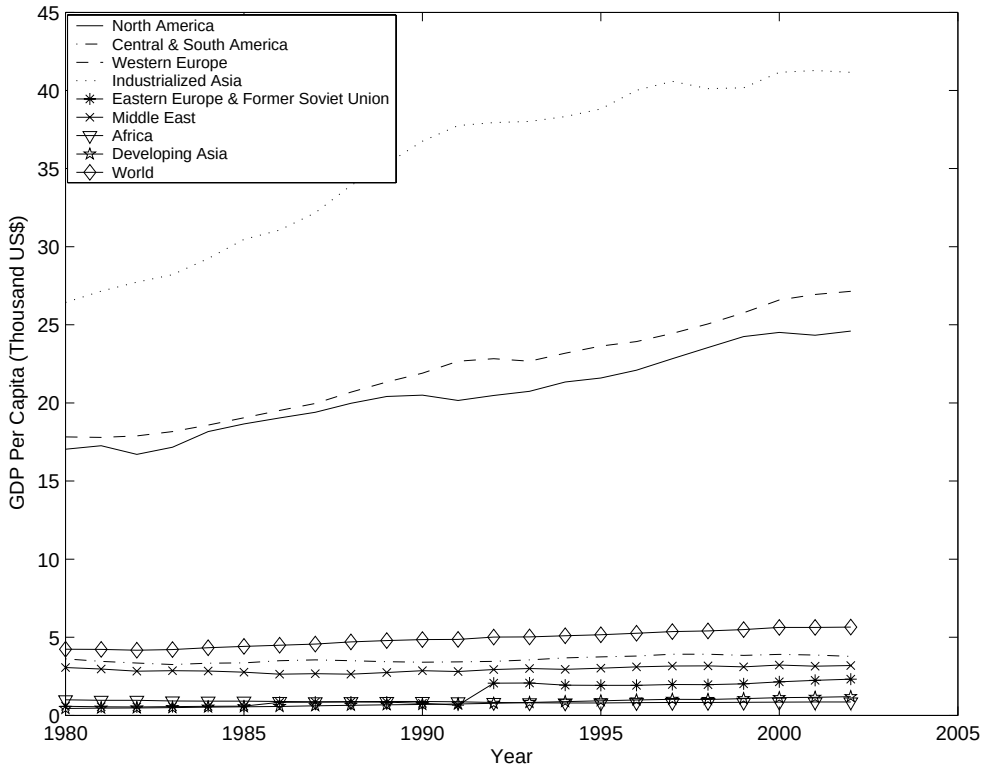

Figure 3 GDP per capita for the regions of the world and world total

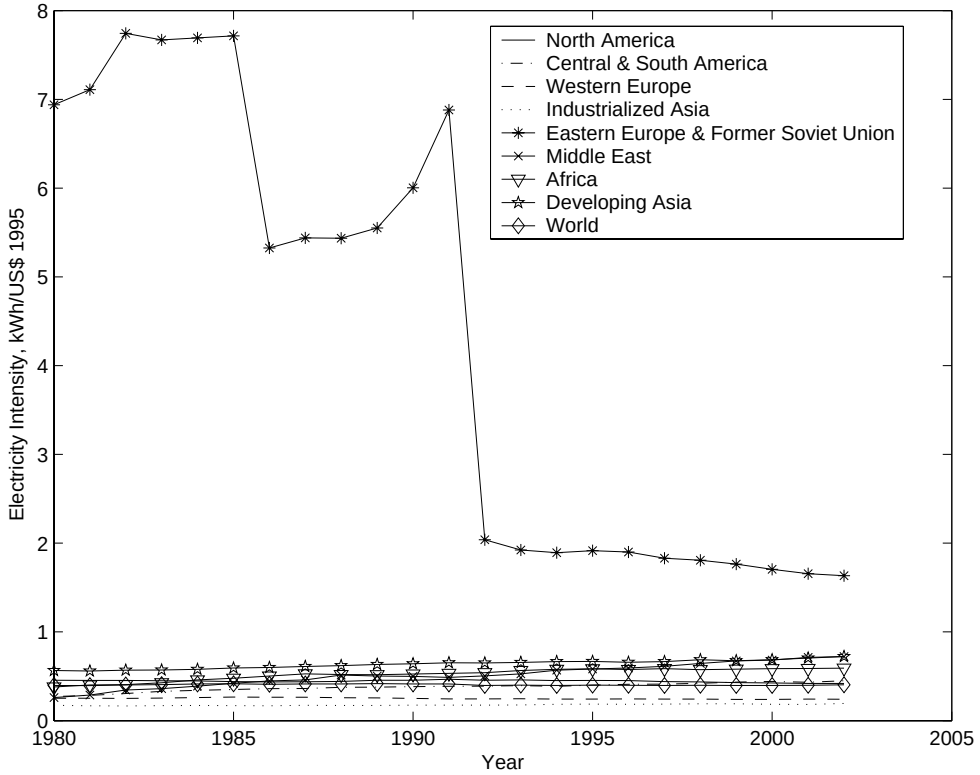

Figure 4 Electricity Intensity for the various regions of the world

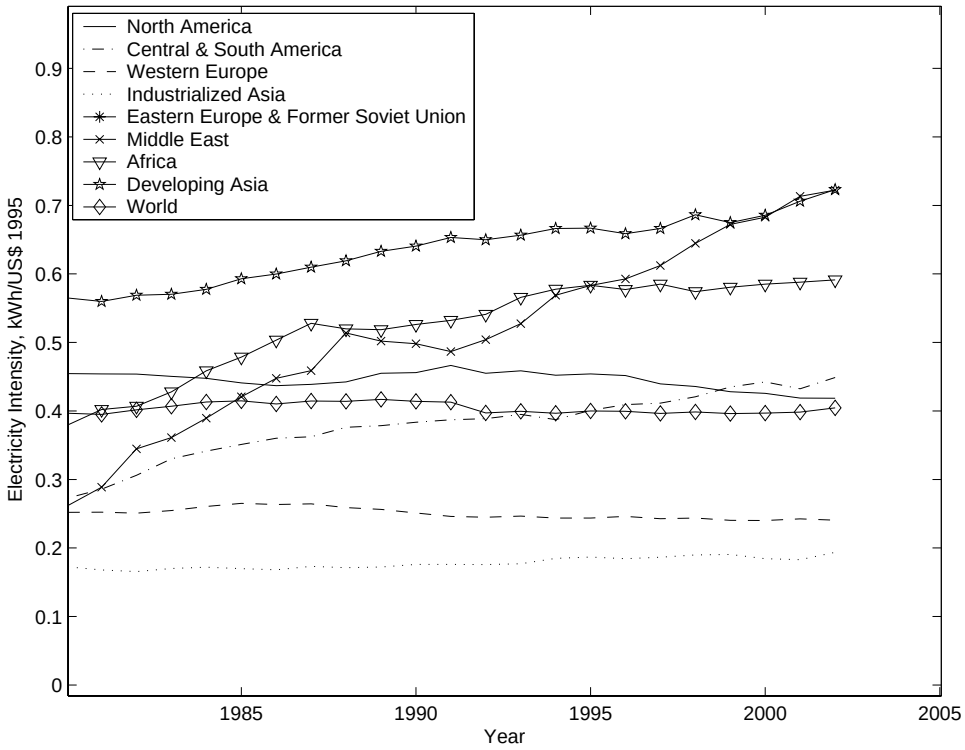

Figure 5 Electricity intensity for the regions (Figure 4 enlarged)

The electricity intensity curves for the regions of the world are shown in Figure 6.

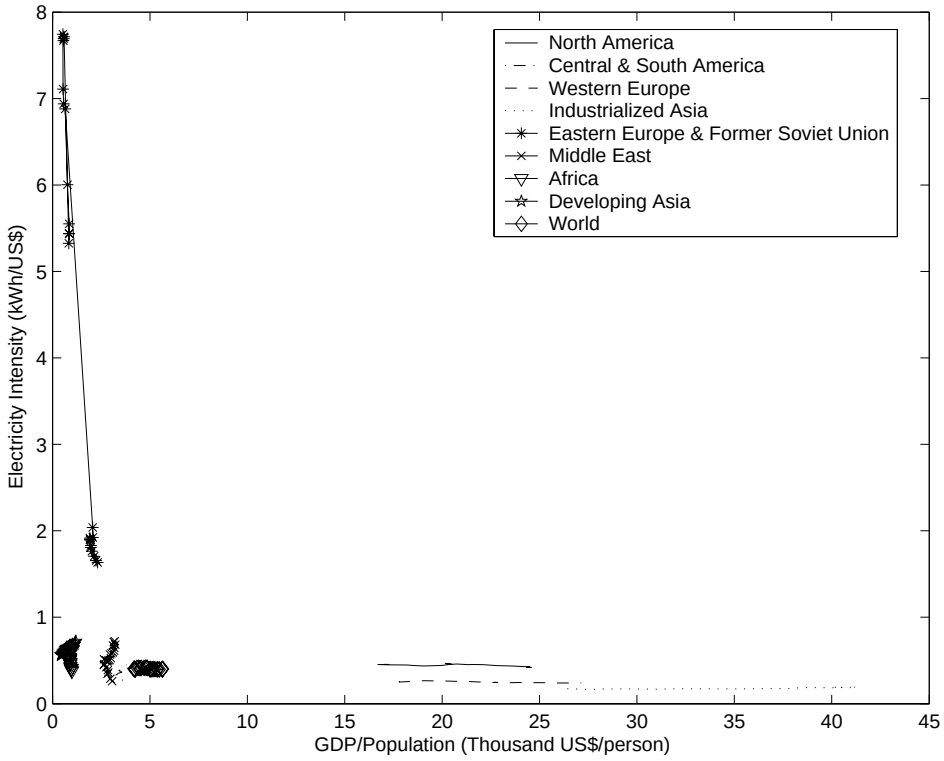

Figure 6 Electricity intensity curves for the regions

A significant gap between the income levels of industrialized regions of the world and the developing world can be observed. The intensity curves for North America, Western Europe and Industrialized Asia are almost horizontal indicating that the economic wealth is achieved without changes in electricity intensity. By contrast, in the developing regions, the per capita GDP is nearly constant and is independent of electricity intensity. The curve for Eastern Europe and the Former Soviet Union is much higher than all the rest. The world average reflects the industrialized regions being horizontal with relatively low values of EI for low wealth per person.

The electricity intensity factors for the regions of the world are shown in Figure 7. Eastern Europe and Former Soviet Union has the highest intensity factor which is rapidly decreasing. The electricity intensity factors for Africa and Developing Asia appear to be converging to a similar level. The intensity factors for the industrialized regions are very low, comparable to each other and at very constant levels over the years. The intensity factors for all the developing regions are above the world average while those for the industrialized regions are below the average.

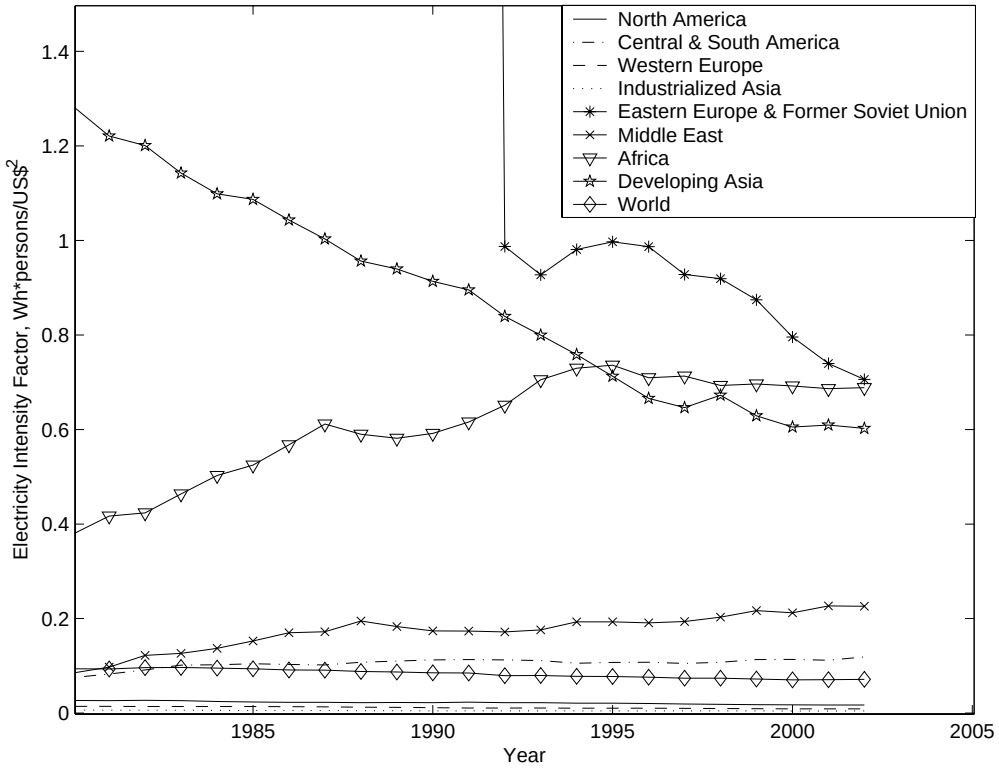

Figure 7 Electricity intensity factors for the regions of the world

5. Electricity Intensity in Selected Countries of the World

In this section, the relationship between electricity consumption, GDP and population of 12 selected countries are analyzed. Figure 8 shows the electricity consumption per capita for these countries. This is highest in the United States while New Zealand

consumes the second highest amount of electricity per person. The electricity consumption per capita in the industrialized countries of the United Kingdom, Japan, Germany, France and Russia are very similar. The electricity consumed in the developing countries is very low compared to the industrialized countries.

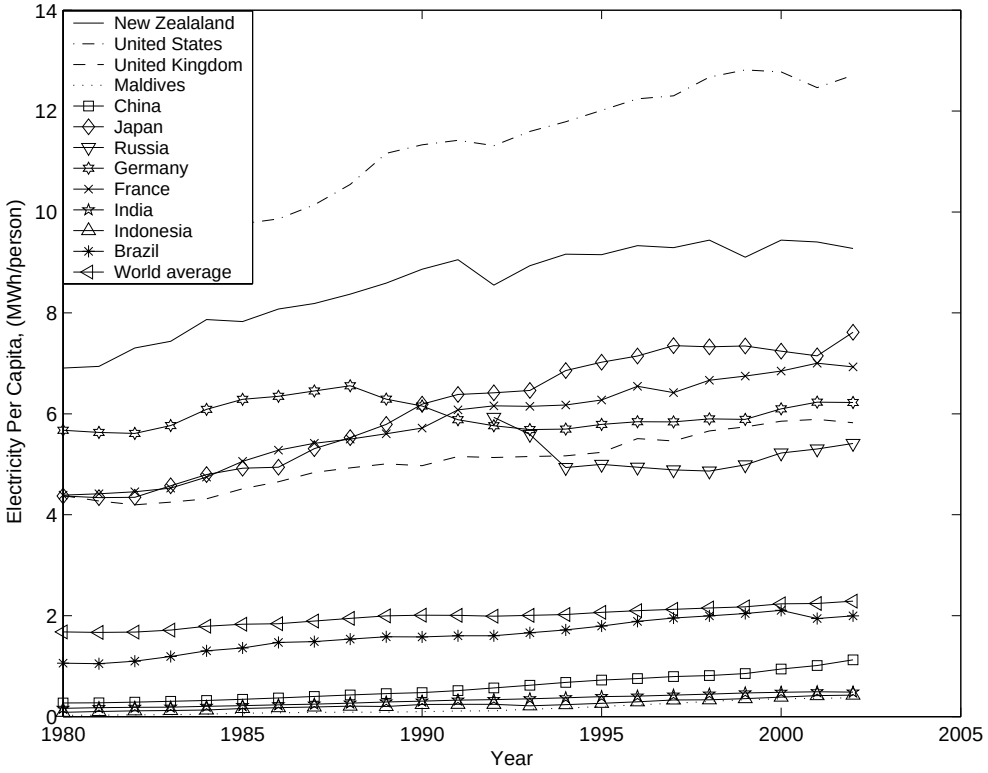

Figure 8 Electricity per capita for the 12 countries

Figure 9 shows the GDP per capita for the 12 countries. Japan shows the highest GDP per capita of the 12 countries presented. The GDP per capita for United States, Germany and France are next with United Kingdom and New Zealand showing very similar patterns throughout the period. The GDP per capita for the developing countries are the lowest.

Figure 10 shows the electricity intensity in these countries. The electricity intensity is highest in Russia. China and India are next. New Zealand has the fourth highest electricity intensity throughout the period. For the other countries, the difference in electricity intensity is small although Indonesia has had a large variation over the period.

The Electricity intensity curves for the 12 countries are shown in Figure 11. The curves are spread out along the two axes. There is a distinguishing pattern in the curves of the industrialized countries and the developing countries. The industrialized countries with high income per capita generally have relatively constant low consumption per dollar of GDP. The developing countries with low, relatively constant, income per capita, have low to high levels of consumption per dollar of GDP.

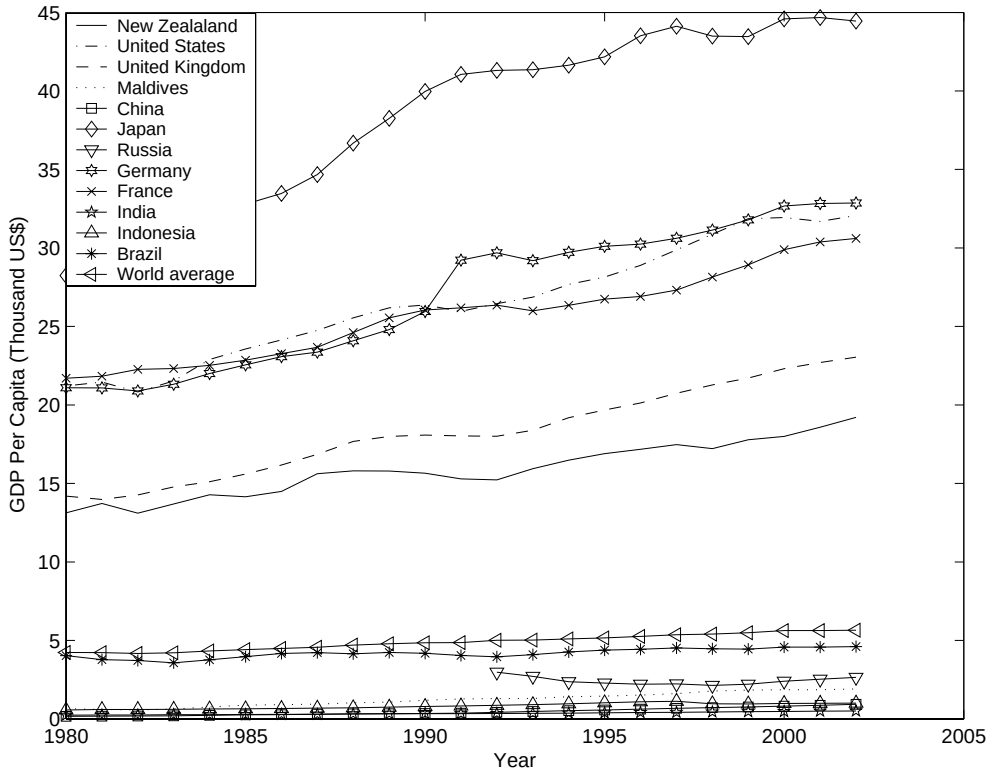

Figure 9 GDP per capita for the 12 countries

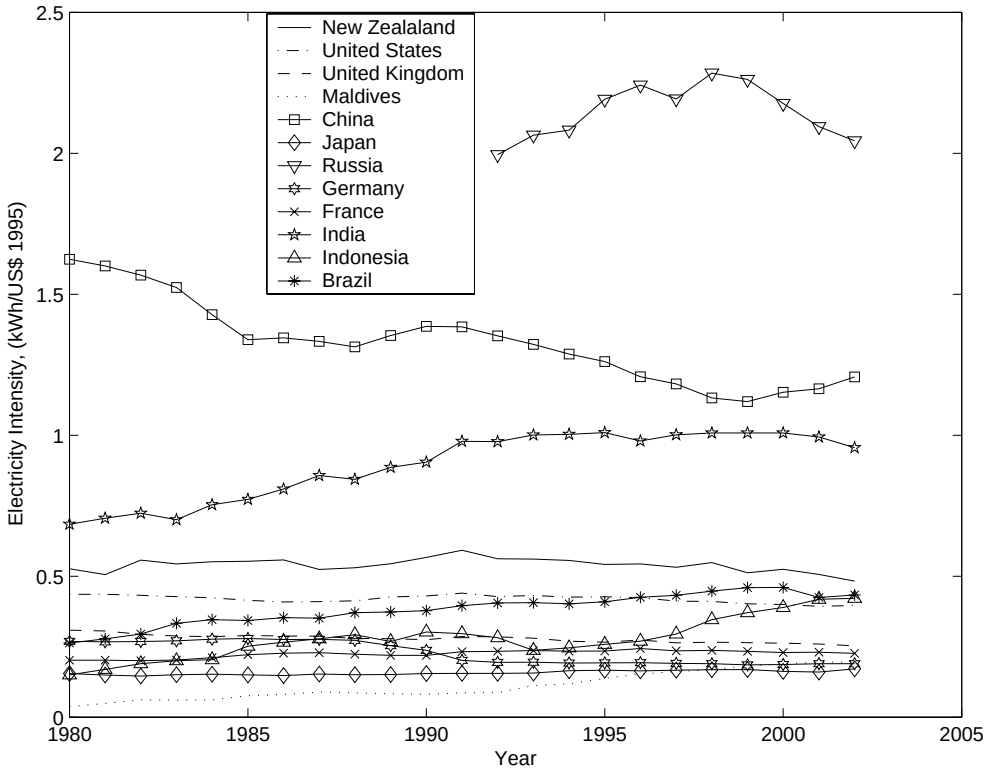

Figure 10 Electricity intensity in the selected countries

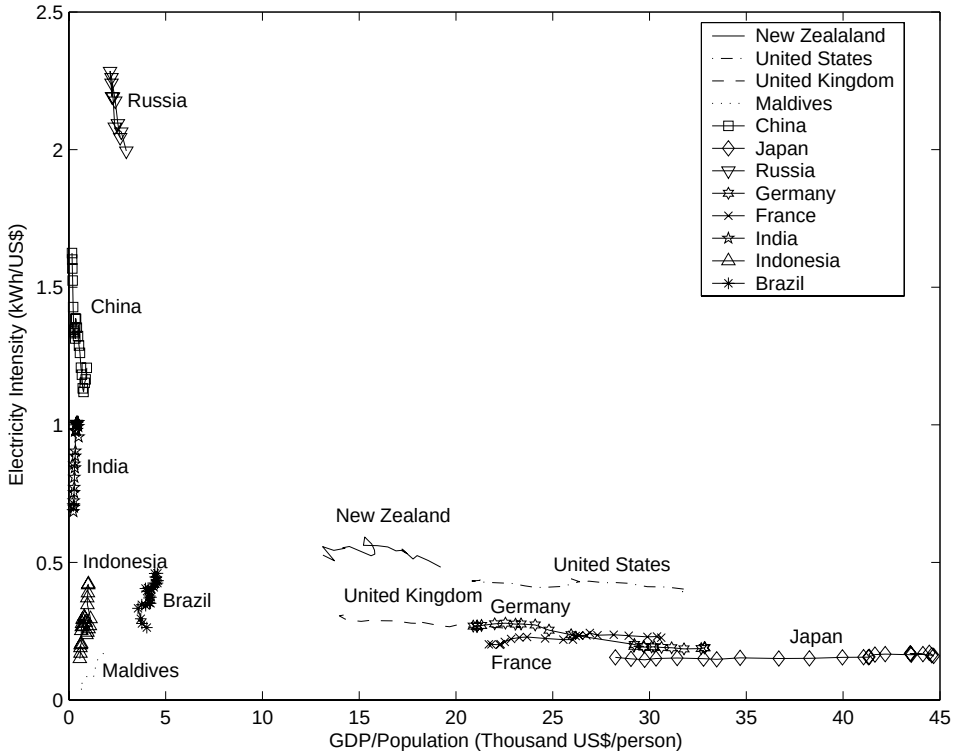

Figure 11 Electricity intensity curves for the selected countries

The electricity intensity factors for the industrialized countries are shown in Figure 12.

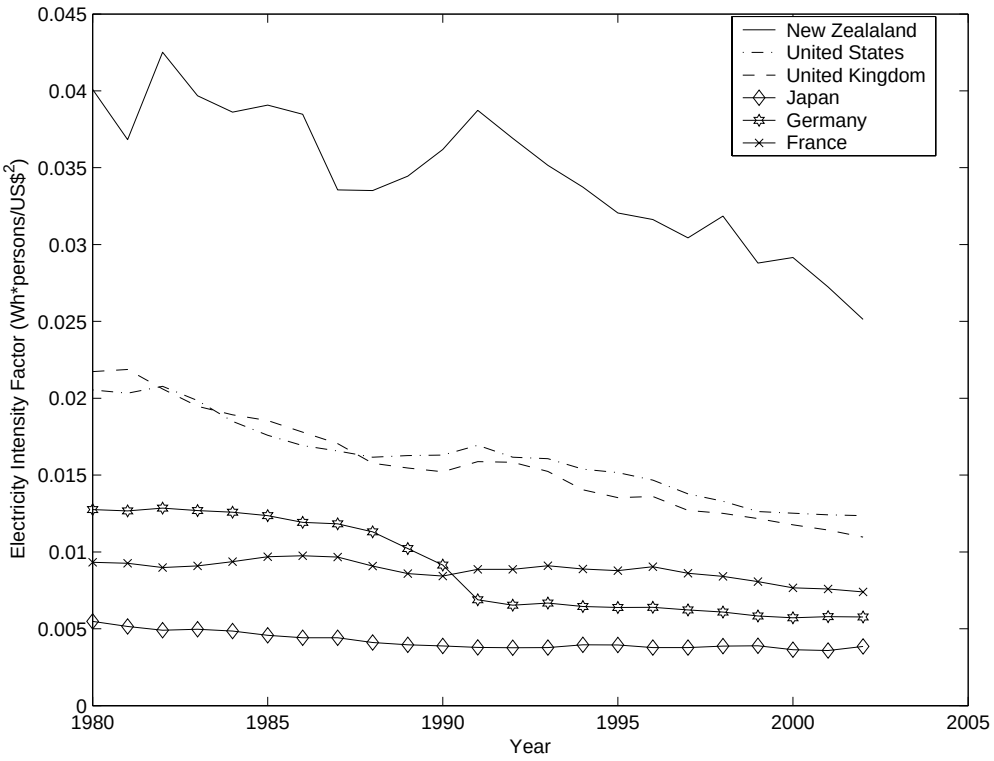

Figure 12 Electricity intensity factors for the industrialized countries

In general, the electricity intensity factors for the industrialized countries have decreased over time. The electricity intensity factors for New Zealand are the highest over the whole period, while the United States and the United Kingdom have similar levels. Japan shows the lowest electricity intensity factors. The sudden drop in electricity intensity for Germany from 1992 is because electricity consumption data for Germany after 1992 includes those for West and East Germany. However the GDP data for East Germany prior to 1992 was not available. Therefore, the GDP data for Germany before 1992 is less than it should have been due to the unavailability of this data. Overall, for the industrialized countries the electricity intensity factors are converging.

The electricity intensity factors for the developing countries are shown in Figure 13. In China, the EIF has decreased dramatically. In India, the factor has decreased slightly over the years. Overall the electricity intensity factors appear to be converging in a similar manner to those for the industrialized countries, but to a much higher level.

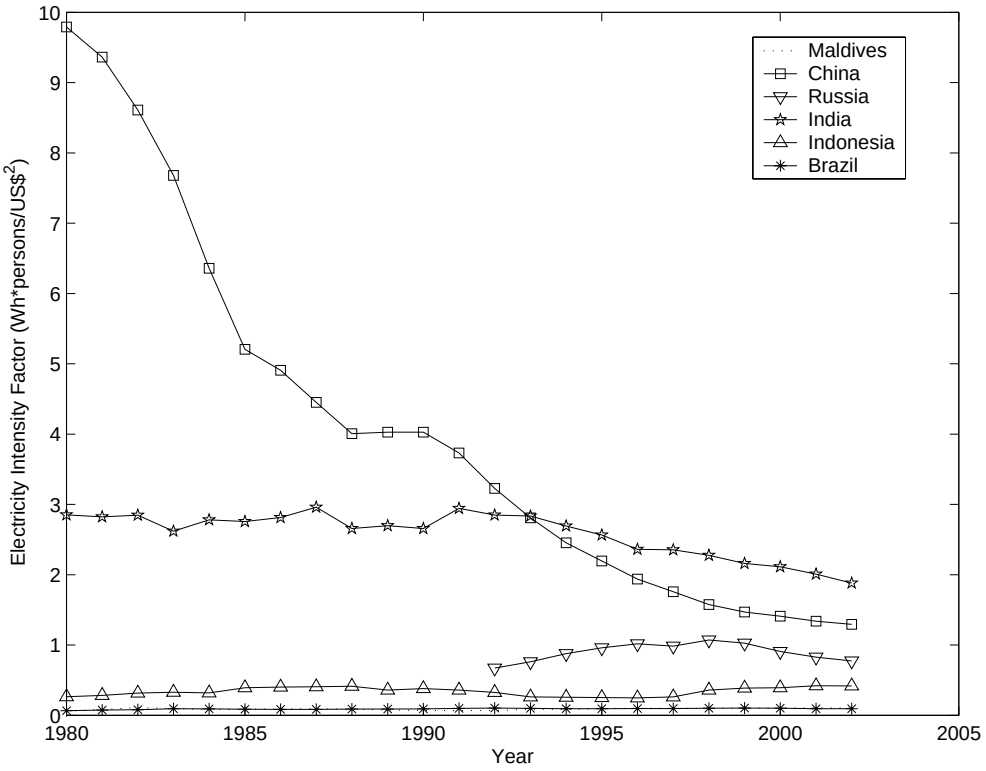

Figure 13 Electricity intensity factors for the developing countries

The electricity intensity, and thus the electricity intensity curve and electricity intensity factors, is higher for New Zealand than the other industrialized countries. The high electricity intensities in some countries have been explained with regard to availability of inexpensive hydro capacity [2]. Hydroelectricity accounts for 55% of the total electricity generated in New Zealand whereas the next competing industrialized country, France, has only 14% of its total electricity generated using hydropower. On the other hand the other industrialized countries have a significant percentage of nuclear, whereas the developing countries have little. Perhaps as China and others develop, this energy source may be used further.

The high electricity intensity in New Zealand relative to other industrialized nations may also be the result of high electricity consumption in residential homes. In general, electricity is used for all residential purposes including water heating, air conditioning and cooking. In many of the developed countries natural gas is used for water heating, room heating and cooking. It may also be due to the electricity intensive industries (EIIs) such as aluminium smelter, steel and pulp, and paper mills.

Electricity prices and relative fuel prices play an important role in locating electricity intensive industries, and the choice of energy carrier and space heating [2]. However it has been found that the electricity price does not affect electricity efficiency significantly in the household and service sectors [2]. This was supported by the fact that the energy intensities in several countries have continued to decrease when energy prices have been falling.

6. World Total Forecasts

The world total electricity consumption is shown in Figure 14. The pattern is smooth and increasing indicating that it can be modelled independently from all factors other than time.

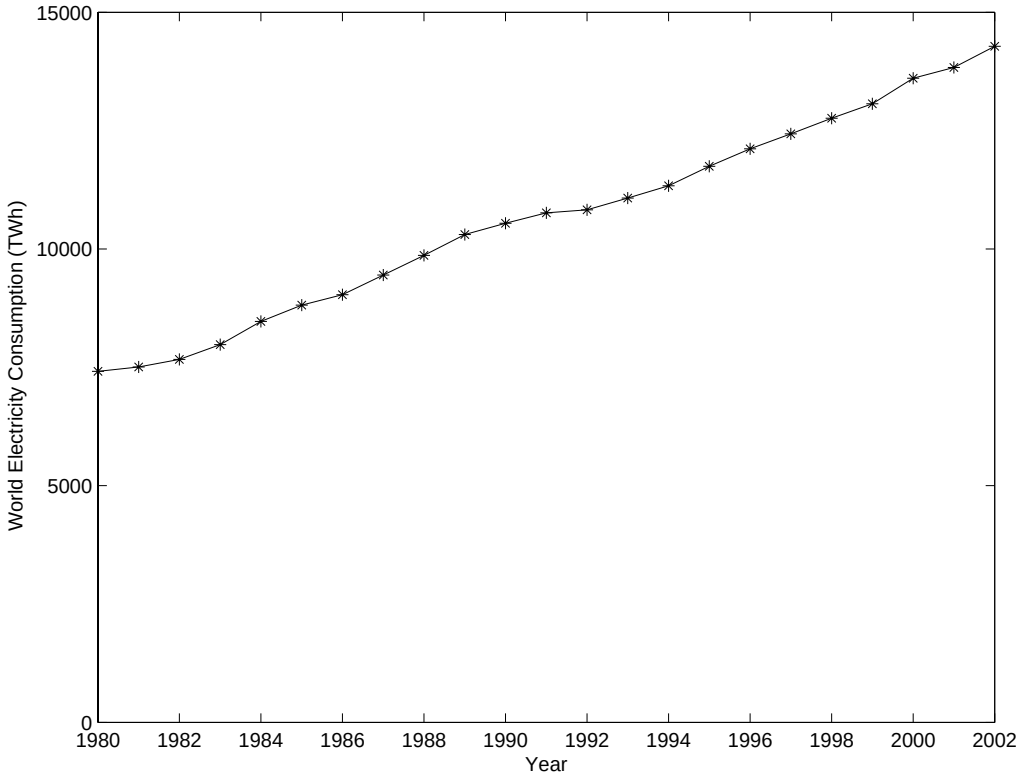

Figure 14 World Total electricity consumption from 1980 to 2002

Six electricity forecasting models have been developed and applied to electricity consumption [3-7]. They are the Logistic model, Combined model, autoregressive integrated moving average (ARIMA) model, Harvey Logistic model, Harvey model and Variable Asymptote Logistic (VAL) model. They are all variations of time series extrapolation techniques. Figure 15 shows the world total electricity consumption as forecasted using five of the models. The VAL model was not applied to the world data due to the availability of a limited number of data points. The Logistic, Combined and ARIMA models gave relatively similar forecasts for fifteen years ahead. The Harvey model predicted the highest rate of consumption.

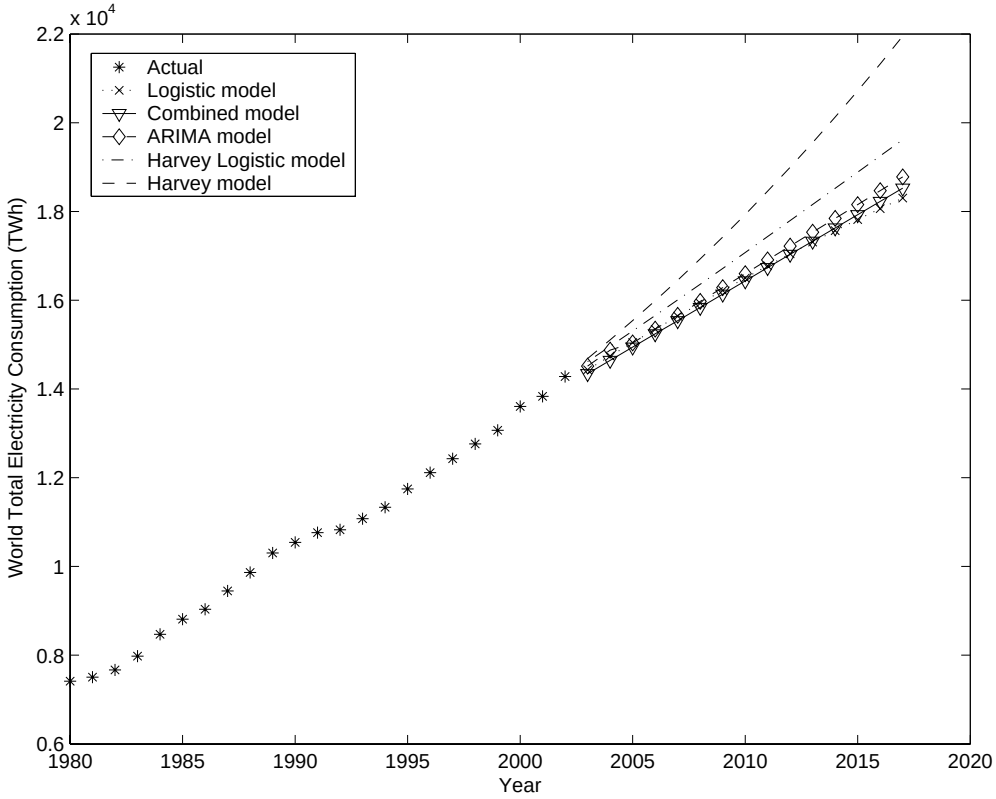

Figure 15 Comparison of forecasts for world total electricity consumption

It is expected that much of the growth in electricity demand in the world would come from the developing countries. Although the developing countries account for more than 75 percent of the world population, the electricity consumption in these countries is only one-third of the world's electricity consumption [8]. The developing countries are expected to have a robust economic growth in the coming years. This requires access to reliable supplies of electricity. As a result, various strategies have been implemented such as privatization to increase investment in the electricity industry and enacting government policies to encourage investment from potential foreign participants [8]. In addition, rural electrification schemes are expected to be introduced both to improve the standard of living and to increase the productivity of rural communities. The growth in electricity consumption in the industrialized world is expected to increase more slowly. The mature electricity sectors and gains in equipment efficiency in the industrialized countries are expected to slow down the growth in electricity consumption.

Despite these expectations it is not necessary to know their details for modeling as the combined effect is that electricity consumption is increasing independent of them. The impact on energy resource requirements to generate the electricity consumption is obvious as is the generation of by products that effect the environment.

7. Forecasting Electricity Consumption in New Zealand

7.1. Electricity Intensity in New Zealand

The electricity consumption for New Zealand from 1943 to 1999 is shown in Figure 16. The electricity consumption data are divided into Domestic and Non-Domestic sectors. There is an increase in trend in the consumption data for all the sectors. The patterns have been relatively smooth despite the myriad of factors that might be considered as influences. These factors are not needed to model the patterns. In terms of larger trend changes, the rate of consumption growth is generally very slow in the Domestic sector especially from 1975 onwards. It is considered that during the early 1970's domestic electricity consumption grew rapidly mainly due to the conversion to electric space heating, the near universal use of electric water heating, and the widespread use of appliances such as washing machines and television sets [9]. However, during the late 1970's electricity consumption dropped noticeably, attributed to a downturn in the economy combined with high electricity prices [9]. Coal and natural gas attracted some of the demand. The effect of restrictions on electricity use brought by the prolonged drought sequence from November 1991 to June 1992 can be clearly seen on all sectors, with a sudden decrease in electricity consumption for 1992.

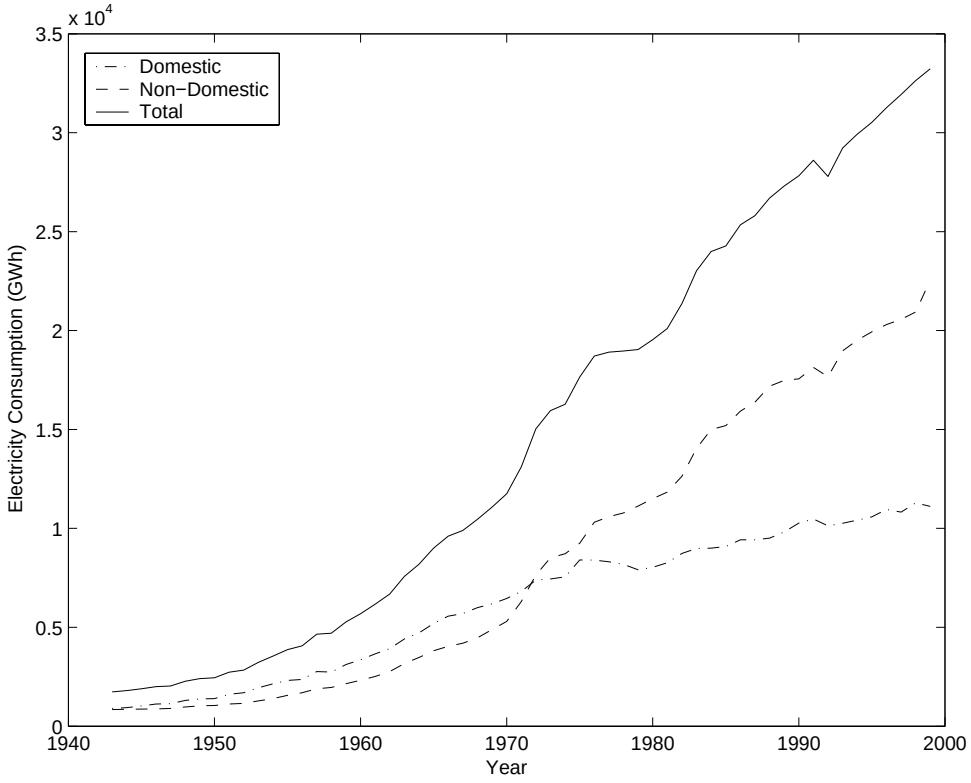

Figure 16 Electricity consumption in New Zealand

Figure 17 shows the electricity per capita, electricity intensity, electricity intensity curve, and electricity intensity factors for New Zealand from 1980 to 2002. The per capita electricity consumption has increased except in the last few years. The electricity intensity has peaked around 1991 and has been declining in the latter years. The electricity intensity curve is similar, indicating that the electricity industry in New Zealand has gone through the early phase of growth, matured and is now in the ageing phase. The electricity intensity factor in New Zealand has decreased over the entire period indicating a reduction in intensity per unit of wealth creation. Electricity is declining in importance relative to economic wealth.

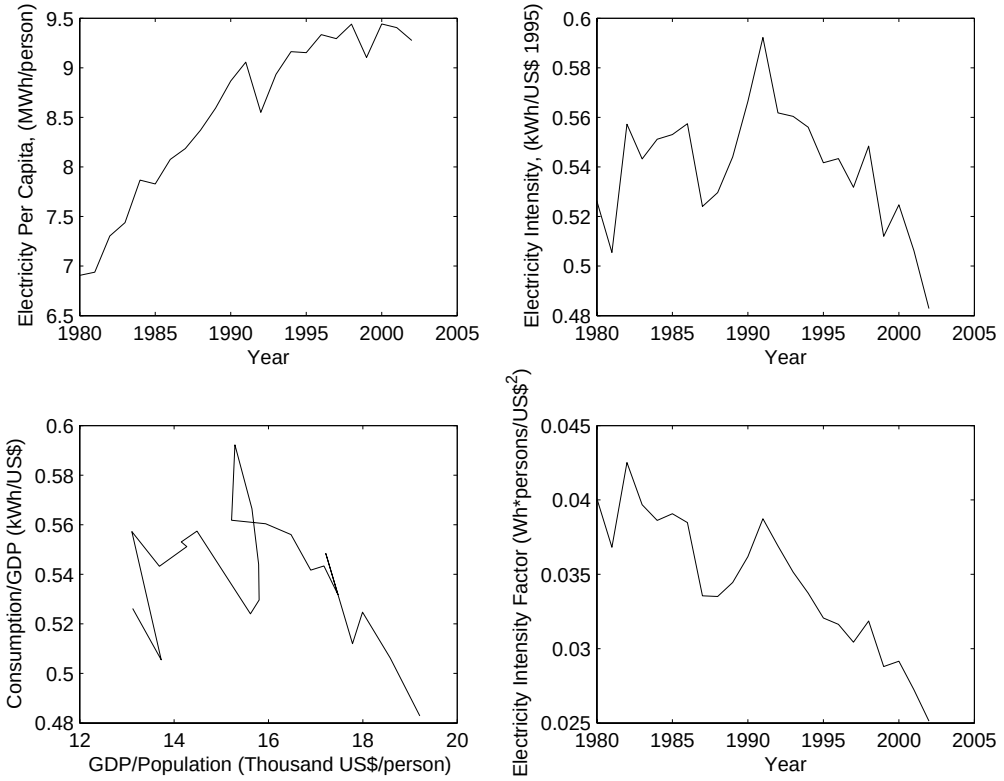

Figure 17 Electricity per capita, intensity, intensity curve and intensity factors for New Zealand

7.2. Deregulation of the New Zealand electricity industry

New Zealand began with the process of deregulating its electric power industry in 1987 aiming to transform the country to a greater free-market economy. In 1993, a transmission corporation was created and monopolies in local distribution and retailing were eliminated. A new electricity policy designed to create a competitive electricity market was also issued in 1995.

The Electricity Industry Reforms Act 1998 required electricity distribution companies to separate line and supply business by 31 December 2003 [10, 11]. Most companies decided to retain their lines business and sell their retail business. TransPower, a state-

owned transmission system enterprise, is responsible for operating the national grid and to contact with users for new investment opportunities [11].

The Electricity Industry Bill was passed in August 2001. The Bill amended the Ministry of Energy Abolition Act 1989, the Commerce Act 1986, the Electricity Act 1992 and the Electricity Industry Reforms Act 1998. The Commerce Amendment Act 2001 allowed the Commerce Commission to control the price revenue of electricity line businesses and to take over the administration of the electricity information disclosure regime. The Electricity Amendment Act 2001 allowed the government to establish by Order as a Crown entity, an Electricity Governance Board and provided the government with the power to make regulations on a number of matters like the requirement to provide domestic consumers with a low fixed charge tariff option [10]. The Electricity Industry Reform Amendment Act 2001 relaxed the rules on the ownership of the electricity generation by line companies and enabled unlimited ownership of renewable generation. The sale and purchase of wholesale electricity in New Zealand is organised by the participants in a private sector wholesale market [10].

Despite these amendments, reforms and changes, deregulation has had no significant effect on the electricity consumption patterns in New Zealand in the long term. Price variation, one of the reasons deregulation was introduced, has had no long term effect on the patterns either.

7.3. New Zealand forecasts

In New Zealand, electricity consumption forecasts have been published by the Centre for Advanced Engineering (CAE) [12] and the Ministry of Economic Development (MED) [13]. These and the forecasts obtained by all the developed models of Section 6, from the year 2000 to 2015 for the Domestic, the Non-Domestic and the Total electricity consumption, are shown in Figure 18 to 20 respectively.

For the Domestic sector, the highest forecasts are given by the MED and the CAE models. The best of the developed models based on data fit accuracy is the Harvey model which gave forecasts in the mid range of the spread.

For the Non-Domestic sector, the CAE model and MED model forecasts are again very similar and compare with forecasts obtained from the Harvey Logistic model, which was the most accurate model fitted to the Non-Domestic data.

For the Total consumption, forecasts given by the Harvey model are very comparable with the CAE and the MED model forecasts. A comparison of the accuracies by the six developed models for New Zealand indicated that the Harvey model is the most accurate model to fit the actual data. This model gave an average error of just over 1% over the historical data, while the second best model (ARIMA) gave a 1.5% forecasting error for the Total electricity consumption of New Zealand. This analysis has revealed that while ARIMA and regression techniques using economic and demographic factors are well known in electricity forecasting, the simple growth curve models are as accurate and hence may play a significant role in forecasting electricity consumption.

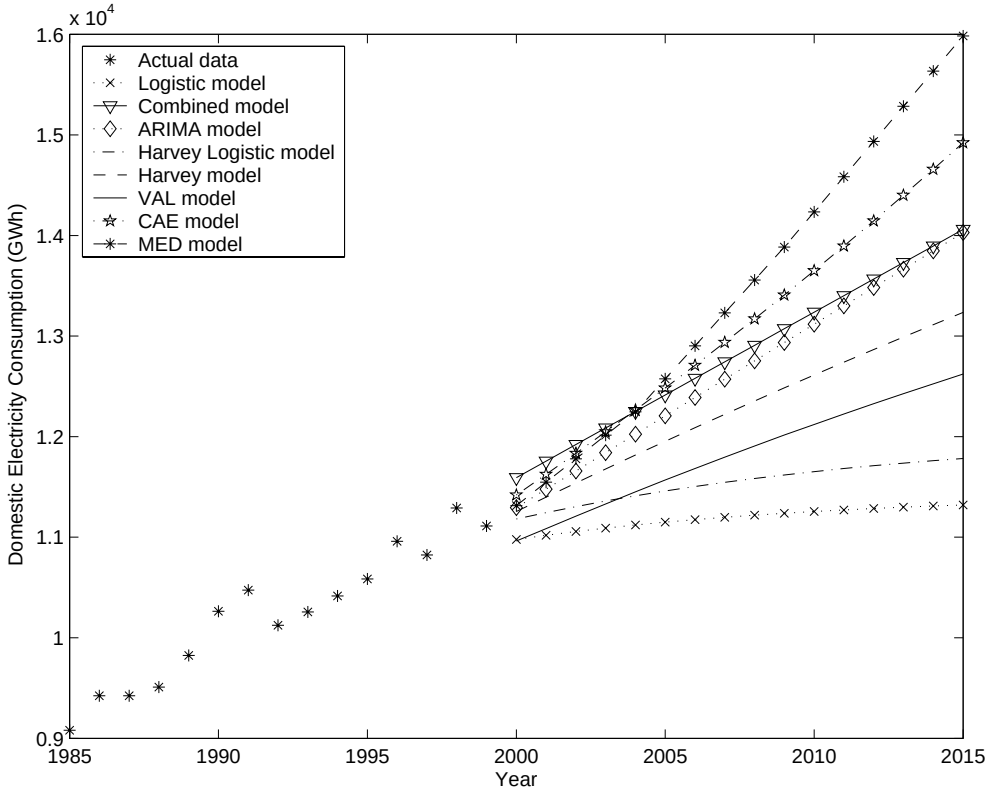

Figure 18 Comparison of forecasts for Domestic sector of New Zealand

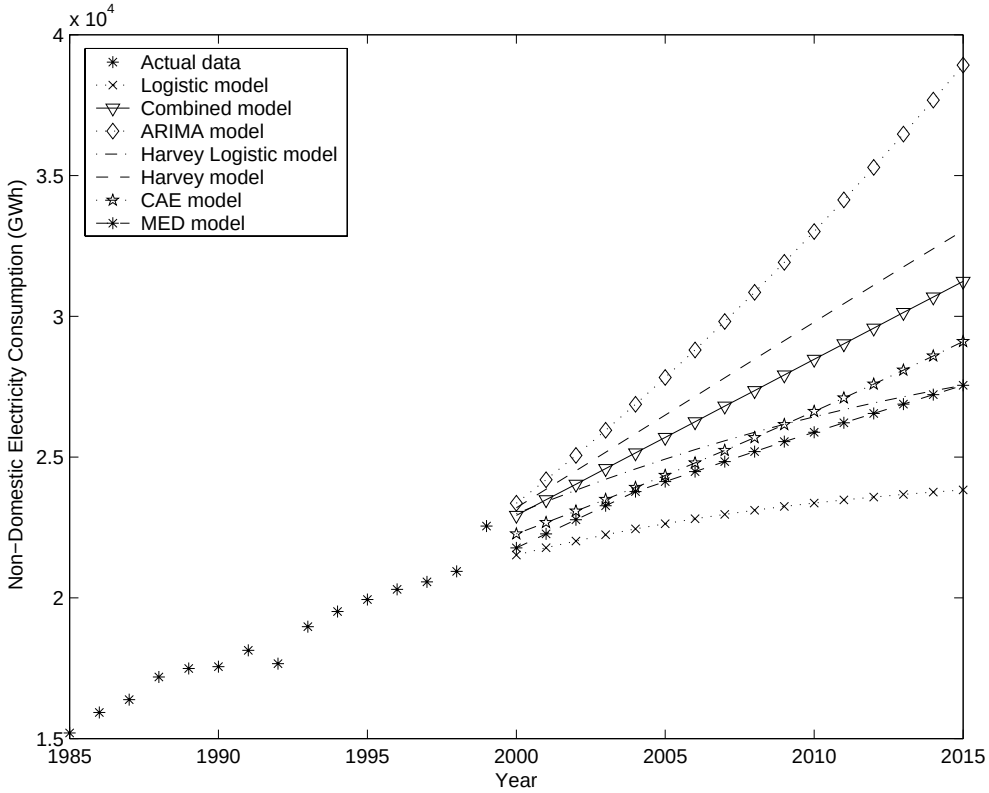

Figure 19 Comparison of forecasts for the Non-Domestic sector of New Zealand

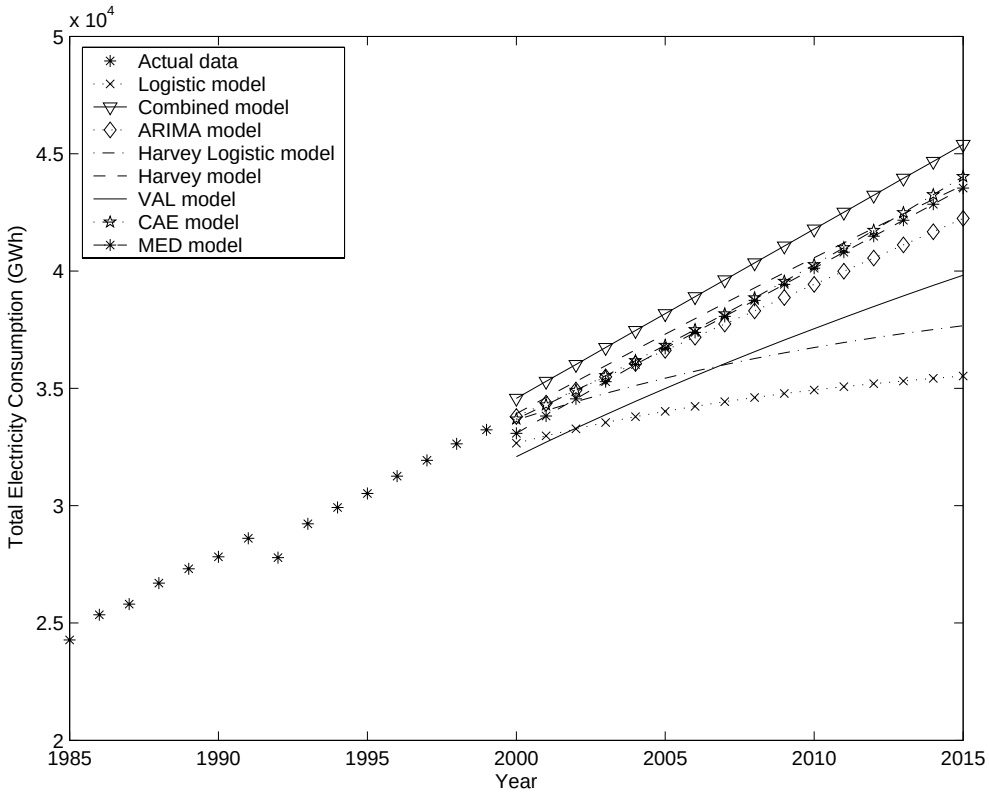

Figure 20 Comparison of Total electricity consumption forecasts for New Zealand

8. Conclusions

This paper has investigated the patterns of electricity consumption in the regions of the world and selected countries of the world. The relationship between economic growth and electricity consumption has been investigated using electricity intensity, electricity intensity curves, and electricity intensity factors. The link between economic growth and energy demand is strongly influenced by the stage of the development and the standard of living in a given region. It was found that the link between economic growth and electricity consumption is stronger in developing countries than those for industrialized countries. In the developing countries, the economies grow as more new industries that generally contribute to economic wealth emerge. In the industrialized countries, although the energy consumption remains high, energy use is more stable or slowly changing. In addition, the chances for increased efficiency, due to replacement of old equipment with modern equipment, in the industrialized countries are higher than those for the developing countries. This has contributed to a reduction in the energy intensity of the industrialized countries. A general trend of a decreasing intensity in the industrialized countries and increasing intensity in the developing countries has also been observed.

The paper has also presented the special case of New Zealand electricity consumption. Forecasts by some developed models are presented to show what the electricity consumption in the world and New Zealand could be in the future.

References

1. Bodger, P.S., Electricity intensity factor: An alternative long term forecasting model, IPENZ Conference, Hasting, New Zealand, Paper 48/84, February 13-17, 1984.
2. Nilsson, L.J., Energy intensity trends in 31 industrial and developing countries 1950-1988, *Energy*, Vol. 18. No. 4, p.309-322, 1993.
3. Mohamed, Z., and Bodger, P.S., Analysis of the Logistic model for predicting New Zealand electricity consumption, Proceedings of the Electricity Engineer's Association (EEA) Conference, Christchurch, New Zealand, June 2003.
4. Mohamed, Z., and Bodger, P.S., A Comparison of Logistic and Harvey models for electricity consumption in New Zealand, *Technological Forecasting and Social Change*, Accepted for publication, Available online at www.sciencedirect.com
5. Mohamed, Z., and Bodger, P.S., Forecasting electricity consumption: A Comparison of models for New Zealand, Proceedings of the Electricity Engineer's Association (EEA) Conference, Christchurch, New Zealand, June 2004.
6. Mohamed, Z., and Bodger, P.S., Forecasting electricity consumption in New Zealand using economic and demographic variables, *Energy*, Accepted for publication, Available online at www.sciencedirect.com
7. Mohamed, Z., and Bodger, P.S., Forecasting electricity consumption: A Comparison of models for New Zealand, Proceedings of the Australasian Universities Power Engineering Conference (AUPEC) 2004, Brisbane, Australia, 26-29 September 2004.
8. Energy Information Administration, *International Energy Outlook 2004*, Washington DC, 2004, Available online: http://www.eia.doe.gov/oiaf/ieo/index.html, on 20 July 2004.
9. Ministry of Energy. Electricity Forecasting and Planning: A Background Report to the 1984 Energy Plan. Private Bag, Wellington, New Zealand, issues 1982 -1984.
10. Ministry of Economic Development – Energy Markets and Policy Group, Resources and Network Branch, *Chronology of New Zealand Electricity Reforms*, July 2002. Online: Available at: http://www.med.govt.nz/ers/electric/chronology/index.html, 8 September 2003.
11. Ministry of Economic Development – Energy Markets and Policy Group, *New Zealand's Electricity Sector*, February 2001. Online: Available at: http://www.med.govt.nz/ers/electric/sector/index.html, 8 September 2003.
12. Sinclair Knight Merz and CAE (Centre for Advanced Engineering, Electricity *Supply and Demand to 2015*, Fifth Edition, University of Canterbury, April 2000, New Zealand.
13. Ministry of Economic Development, Modelling and Statistics Unit, *New Zealand Energy Outlook to 2020*, February 2000, New Zealand.